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Numerical modeling of the conduction and radiation heating in precision glass moulding

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Abstract

Heating the glass wafer until the moulding temperature is the first important step in the glass moulding process and any reduction in time of this heating stage increases the production efficiency, considerably. Depending on the requirements for heating time and temperature uniformity in the glass wafer, heating can be performed by either conduction or radiation. The numerical simulation of these two heating mechanisms in the wafer based glass moulding process is the topic of the present paper. First, the transient heating of the glass wafer is simulated by the FEM software ABAQUS. Temperature dependent material data of the glass wafer are taken into account in the simulation to have a more realistic model of the material. Heating curves depicting temperature as a function of time inside the glass wafer are predicted for both radiation and conduction heating and based on that the heating time and the temperature uniformity in the glass wafer are evaluated for both heating mechanisms. Subsequently, the approximate radiation heat loss from the glass wafer during cooling is calculated using both numerical and analytical methods and the temperature change in the glass wafer versus time is obtained for this stage. The achieved results make way for an increased understanding of the heating process in precision glass moulding and hence a possible improvement of the heating system.

1 Introduction

The demand for lower cost glass lenses along with higher image quality has led the glass lens manufacturers to employ a new technology involving wafer based precision glass moulding. However, the high required accuracy as well as the complexity of this technology calls for a high level of process understanding and numerical simulation is a very important part of achieving this goal. The effect of the glass temperature distribution on the quality of the manufactured product in terms of final properties and induced residual stresses and deformations necessitate a proper modeling of the heat transfer in the process. The heating stage in precision glass moulding can be performed either by infrared radiation or conduction heating. Several contributions have been given in literature to simulate the conduction heating for prediction of the glass temperature in the glass moulding process [1-3]. It is normal procedure for such type of calculations to neglect the interface radiation and the temperature dependence of the thermal conductivity and heat capacity in the glass wafer, however [4] is the first work in literature which takes these phenomena into account in a detailed way. Moreover, no work has so far been made with the purpose of comparing and evaluating the two different heating mechanisms of radiation and conduction in precision glass moulding with respect to heating time and temperature uniformity. The present work which is based on the newly developed model presented in [4] is addressing this topic for an existing conduction heating system in industry.

2 Numerical simulation

Considering only the heating stage of the moulding process, when there is no material deformation, the temperatures can be found from the solving the heat conduction equation (1) along with proper conduction and radiation boundary conditions.

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + Q_V \tag{1}$$

where k, C_p and Q_V are thermal conductivity, specific heat capacity and body heat generation, respectively. A combination of both radiation and conduction heat transfer is considered in the surface interfaces. For each surface pair with radiation interaction in the ABAQUS model, the interface heat transfer is given by:

$$\mathrm{q} = \frac{\sigma}{\left(\frac{1}{\varepsilon_{\mathrm{slave}}} + \frac{1}{\varepsilon_{\mathrm{master}}} - 1\right)}\left(\mathrm{T_{slave}}^4 - \mathrm{T_{master}}^4\right) \tag{2}$$

where "σ" is the Stefan-Boltzmann constant (5.67×10^{-8} W/m^2/K^4). "ε_{slave}" and "ε_{master}" represent the slave and master surface emissivities in the contact pair.

2.1 Conduction and radiation heating systems

The heating process of an LBAL-42 glass wafer (d=50 mm, t=1.5mm) is simulated in a conduction (power = 2000 W) and a radiation heating system (power = 400 W), respectively, see Figures (1) and (2). The temperature curves in the middle and the side points of the glass wafer for 500 seconds of heating are shown in Figure (3). As seen, the temperature difference between the side and the middle point for the infrared heating system is considerably higher than that of the conduction heating system. The corresponding temperature differences are 4 C° and 57 C°, respectively.

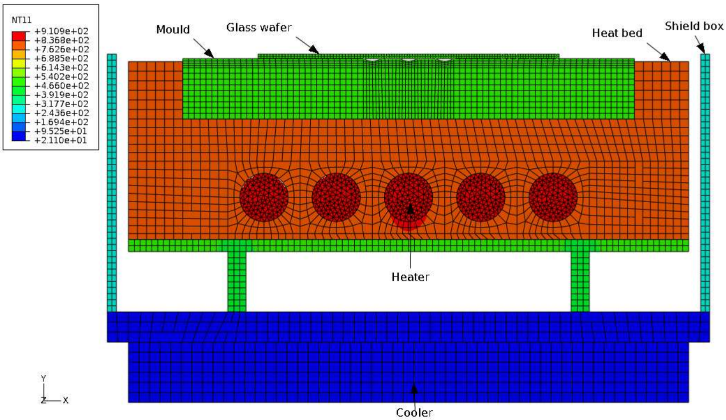


Figure 1: FE model of the conduction heating system of 2000 W heat power

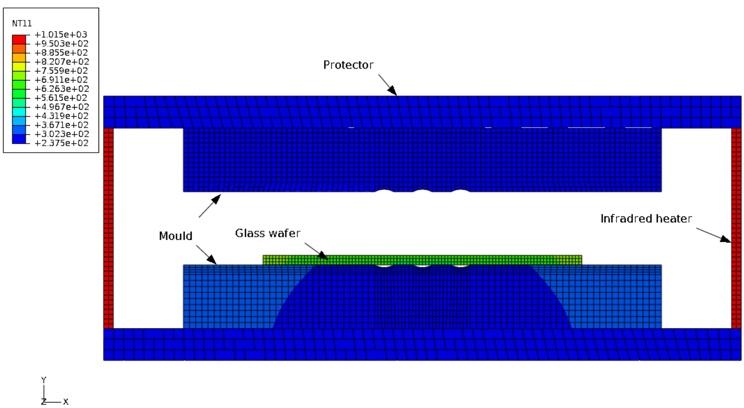
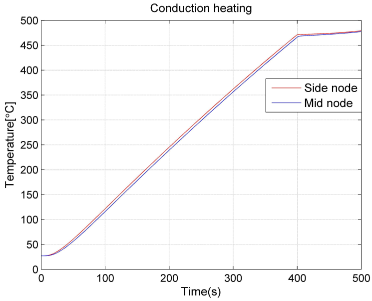


Figure 2: FE model of the radiation heating system of 400 W heat power



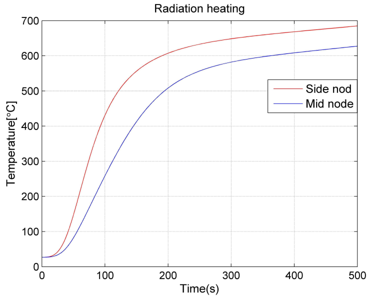


Figure 3: Temperature curves of the side and middle points in the glass wafer (a) conduction heating system (vacuum after 400 seconds) (b) radiation heating system

It is obvious that the temperature uniformity in the current conduction heating system is significantly higher than that of the radiation one. On the other hand, compared to the radiation heating, the required power of the conduction heating system (2000 W) to increase the glass temperature to a certain level is considerably higher.

2.2 Glass radiation to the ambient during cooling

Figure (4) shows both numerical and analytical results for the temperature as a function of time during cooling of the glass wafer through radiation to the ambient of 27 C°. The analytical temperature results are obtained from a simple lumped analysis via MATLAB programming [5]. The higher cooling obtained from this analysis comes from the simplification made in the calculation of the equivalent radiation heat transfer coefficient.

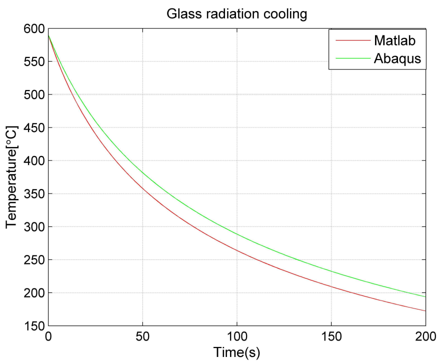


Figure 4: Temperature drop in the glass wafer due to radiation to the ambient

3 Conclusion

The two major parameters of heating time and temperature uniformity in the heating stage of precision glass moulding were investigated with numerical simulation for both conduction and radiation heating systems. It was found that compared to the infrared radiation system, the temperature uniformity for the current conduction heating system is higher, however on the cost of using more power. Furthermore, the temperature drop in the glass wafer during cooling through radiation to the ambient was examined by both analytical and numerical methods. The presented analysis could be used as the basis for an optimization procedure and hence make way for a new and efficient design of the radiation heating system.

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